Colour Change of Nordic Scots Pine Wood under UV Radiation
Laboratory Approach
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BACKGROUND
- Issues of visual harmony, easiness to look at, and balance of features and colours are said to have
  importance in people's impression and valuation of wood.
- Due to the large natural colour difference, one major factor causing imbalance and disturbance in
  wooden surfaces made of pine is the simultaneous presence of sapwood and heartwood.
- In several indoor end-uses colour is affected by filtered solar radiation.
  - When studying the ultraviolet-visible light-infrared part of the spectrum, it is the UV part
    that mainly affects the colour of wood.
  - Due to absorption in the atmosphere only the UV-A part can reach the earth's surface and affects
    materials in outdoor uses.
  - In indoor conditions the effective spectrum of radiation is even narrower, thus the radiation is
    again absorbed, now by the window glass.
- In this study, the aim was to determine the colour change of Nordic Scots pine (Pinus sylvestris) wood
  caused by UVA-351 type fluorescent lamps in rapid exposure test simulating indoor end-uses.

EMPirical MATERIAL
- A sample of 60 mature Scots pine-dominated stands from mineral soils in five regions in Finland and
  Sweden, 12 stands from each (Fig. 1).
- In each stand, three randomly selected Scots pine trees covering the diameter range of conventional
  saw log and small-diameter log trees (DBH≥14 cm).
- 486 specimens were cut from the sections of butt log, middle log, and top log (at 2, 6, and 10 m) from
  each sample tree.

METHODS
- Specimens were irradiated with UVA-351 type fluorescent lamps under constant conditions
  (+20°C; RH 65%) using cyclical test procedures:
  1° period t1-t5, 4h ON - 2h OFF, total 1000h irradiation
  2° period t6-t10, 5h ON - 1h OFF, total 1000h irradiation.
- Colour of wood was measured separately from sapwood and heartwood at t6-t10, and t5 by spectral
  reflectance method.
  - Spectrophotometer with D65 standard illuminant and 2° standard observer was used.
  - Reflection spectrum in the 400–700 nm region was obtained, and the CIELAB (L*, a*, and b*)
    colour parameters were computed.
- Differences in colour coordinates between sapwood and heartwood, i.e. ΔL*, Δa*, and Δb*, as well as the total
  colour difference ΔE* were calculated at different points of time.
- Variation in ΔE* was studied by means of linear mixed models.

RESULTS
- Colour coordinates of sapwood and heartwood
  - Reflectance of both sapwood and heartwood decreased considerably during the irradiation
    (Fig. 2).
  - Lightness (L*) of both sapwood and heartwood decreased and redness (a*) simultaneously
    increased during irradiation.
  - Yellowness (b*) increased clearly from t5 to t10, but decreased slightly from t5 to t10 both in sap-
    wood and heartwood.
  - ΔL*, Δa*, and ΔE*, i.e. differences in lightness, redness, and total colour between sapwood and
    heartwood were highest at the time t9, whereas Δb* increased also from t5 to t10 (Table 1).
- Mixed model analysis
  - Square root conversion of ΔE* was used as dependent variable.
- Mixed model with repeated effects structure was built (Table 2).
  - Effect of region, time, and both interactions were statistically significant, whereas height was not
    statistically significant (Table 3).
- Variance component of stand was statistically significant (p = 0.039), whereas tree-level random
  effect, as well as variance and covariance parameters of time/height were insignificant at 0.05 level.
- Based on pair-wise comparisons, only regions 2 and 5 differed significantly from each other.
- In each region and height, the greatest colour differences were found at t9.
  - ΔL*, ΔE* increased towards top of the tree, whereas at t5, and t10, ΔE* was biggest at 2m height.

Figure 1. Location of the sample of 60 stands in Finland and Sweden. Map: Nivala, V. & Lukkarinen, A.
Metsä

Figure 2. Relative reflectance of sapwood and heartwood in the range of visible light before (t0) and after (t1)
irradiation (average±standard deviation). For clarity the standard deviations are drawn only in one direction.

Table 1. Differences in colour coordinates between sapwood and heartwood at t6-t10, and t5 (average±standard deviation).

<table>
<thead>
<tr>
<th>Time</th>
<th>ΔL*</th>
<th>Δa*</th>
<th>Δb*</th>
<th>ΔE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>t6-t10</td>
<td>-0.76±0.85</td>
<td>-2.51±0.89</td>
<td>3.55±1.33</td>
<td>6.70±2.21</td>
</tr>
<tr>
<td>t5</td>
<td>2.14±1.21</td>
<td>-1.95±0.87</td>
<td>2.91±1.54</td>
<td>6.40±2.13</td>
</tr>
</tbody>
</table>

Table 2. Estimates of fixed effects. S.E. = standard error, df = degrees of freedom.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>S.E.</th>
<th>df</th>
<th>Parameter Estimate</th>
<th>S.E.</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.767***</td>
<td>0.067</td>
<td>115.082</td>
<td>[Log10(1)] TIME=1</td>
<td>0.427***</td>
<td>0.066</td>
</tr>
<tr>
<td>Region</td>
<td>-0.192**</td>
<td>0.093</td>
<td>107.267</td>
<td>[Log10(1)] TIME=2</td>
<td>0.039**</td>
<td>0.012</td>
</tr>
<tr>
<td>Height</td>
<td>-0.368***</td>
<td>0.091</td>
<td>100.612</td>
<td>[Log10(1)] TIME=3</td>
<td>0.289***</td>
<td>0.063</td>
</tr>
<tr>
<td>Time</td>
<td>-0.289***</td>
<td>0.090</td>
<td>96.512</td>
<td>[Log10(1)] TIME=4</td>
<td>0.009**</td>
<td>0.012</td>
</tr>
<tr>
<td>Region * Time</td>
<td>-0.139</td>
<td>0.089</td>
<td>94.223</td>
<td>[Log10(1)] TIME=5</td>
<td>0.020**</td>
<td>0.062</td>
</tr>
<tr>
<td>Height * Time</td>
<td>0.110**</td>
<td>0.036</td>
<td>145.531</td>
<td>[Log10(1)] TIME=6</td>
<td>0.015</td>
<td>0.011</td>
</tr>
<tr>
<td>Region * Time</td>
<td>-0.017</td>
<td>0.034</td>
<td>141.458</td>
<td>[Log10(1)] TIME=7</td>
<td>0.147*</td>
<td>0.061</td>
</tr>
<tr>
<td>Height * Time</td>
<td>-0.777***</td>
<td>0.046</td>
<td>180.331</td>
<td>[Log10(1)] TIME=8</td>
<td>0.007</td>
<td>0.011</td>
</tr>
<tr>
<td>Time</td>
<td>0.096***</td>
<td>0.010</td>
<td>207.703</td>
<td>[Log10(1)] TIME=9</td>
<td>0.286***</td>
<td>0.033</td>
</tr>
<tr>
<td>Time</td>
<td>-0.034</td>
<td>0.009</td>
<td>157.144</td>
<td>[Log10(1)] TIME=10</td>
<td>0.009</td>
<td>0.013</td>
</tr>
<tr>
<td>Time</td>
<td>-0.055*</td>
<td>0.026</td>
<td>139.049</td>
<td>[Log10(1)] TIME=11</td>
<td>0.001</td>
<td>0.009</td>
</tr>
</tbody>
</table>

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